

Alkaline Fuel Cell Performance Investigation

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ALKALINE FUEL CELL PERFORMANCE INVESTIGATION

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SUMMARY

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An exploratory experimental fuel cell test program was conducted to investigate the performance characteristics of alkaline laboratory research electrodes. The objective of the work was to establish the effect of temperature, pressure, and concentration upon performance and evaluate candidate cathode configurations having the potential for improved performance. The performance characterization tests provided data to empirically establish the effect of temperature, pressure, and concentration upon performance for cell temperatures up to 300 °F and reactant pressures up to 200 psia. Evaluation of five gold alloy cathode catalysts revealed that three doped gold alloys had more than two times the surface area of reference cathodes and therefore offered the best potential for improved performance.

BACKGROUND

The alkaline fuel cell has shown to be a reliable, lightweight, efficient power source for space and terrestrial applications. The system employed in the Space Shuttle Orbiter is capable of providing power-on-demand up to 12 kW within voltage regulation over a useful operating life of 2500 hr. A 30 kW fuel cell unit has been successfully employed in a deep-diving submersible.

Orbiter-type fuel cells, under a NASA Lewis Research Center sponsored technology improvement program, have demonstrated 18 000 hr of operation without significant performance degradation. The load profile for the 18 000-hr test simulated the cyclical profile of a fuel cell unit of a regenerative fuel cell system operating in low-Earth orbit. The incorporation of corrosion-resistant cell components, including supported catalyst anodes, potassium titanate matrices, and advanced material cell edge frame into the cell assembly, has shown to extend the endurance capability of the alkaline fuel cell. The use of a porous graphite electrolyte reservoir plate (ERP) as a replacement for the porous nickel ERP would reduce the weight of the Orbiter electrode assembly by nearly 40 percent.

The work accomplished under the NASA technology program has been reported in references 1 to 14.

Future applications for the fuel cell will require a low weight power system capable of delivering very high power. To satisfy these requirements, the

alkaline fuel cell will have to operate at current densities in excess of 1000 ASF, at high cell temperature and reactant pressure, to achieve low cell specific weight and high-power density. Under the NASA technology program, sub-scale laboratory cells have demonstrated the capability to operate at current densities up to 9000 ASF and the capability of sustained operation at 2000 ASF for several hours.

The primary goal of the recent NASA program has been to identify the performance characteristics of the alkaline fuel cell at cell temperatures up to 300 °F and reactant pressures up to 200 psia. From the characterization tests, empirical performance correlation factors were developed to assist the system designer to evaluate the impact of concentration, pressure, and temperature upon performance. An adjunct to this work included the exploratory evaluation of new gold-platinum cathode catalyst. New catalyst systems with more than two times the surface area of the reference cathode catalyst having the best potential for improved performance were identified. This paper describes the results of recent performance characterization testing and catalyst evaluation work.

LABORATORY RESEARCH CELL

Evaluation testing to establish the performance characteristics of the alkaline fuel cell and the exploratory evaluation of new cathode catalyst was conducted in a laboratory research cell.

The research cell shown in figure 1, has an active area of 0.028 ft² with planar dimensions of 2 in. by 2 in. The fuel cell consists of an anode and cathode separated by an electrolyte containing matrix with a porous electrolyte reservoir integral with or adjacent to the anode. A nonunitized Teflon gasket cell edge frame is employed to provide a reactant seal and maintain cell package structural integrity. Stainless steel end plates provide for manifolding of reactants. Reactant flow fields are machined into the plates. A high pin coverage field is employed to minimize electrical resistance. Tabs are provided on each end plate for current collection. The end plates are gold-plated to retard corrosion on all surfaces having potential exposure to potassium hydroxide.

PERFORMANCE CHARACTERIZATION

Performance evaluation tests of laboratory research cells were conducted to identify the effect upon performance of electrolyte concentration, pressure, and temperature. These tests provided the data to empirically establish the effect of these operating parameters at up to 1000 ASF and a method of extrapolating cell performance out to the peak power density of the cell at cell temperatures up to 300 °F, reactant pressures up to 200 psia, and electrolyte concentration to 50 wt % KOH.

The cell configurations for the five laboratory research cells assembled and performance tested are summarized in table I.

Performance evaluation testing established the impact of electrolyte concentration, cell temperature, and reactant pressure upon cell performance. The

performance response to electrolyte concentration variation for cell number 2 is shown in figure 2.

The performance characteristics of cell number 2 at cell temperatures up to 300 °F and reactant pressures up to 200 psia are shown in figure 3. The data presented has been adjusted for cell internal resistance measured at 4.5 mV at 100 ASF. At 300 °F and 200 psia, a 92-mV improvement was obtained over the performance achieved at reference operating conditions of 180 °F and 60 psia.

PERFORMANCE CORRELATION FACTORS

Empirical performance factors were established from performance characterization testing of laboratory research cells. The performance correlation factor for concentration was determined by plotting cell performance versus operating concentration at constant load. The performance correlation factors for pressure and temperature were arrived at by plotting Tafel data on semi-log grid graph paper with the log of the voltages versus the reciprocal of pressure and temperature at constant load. The results of the data reduction process are presented in figure 5, correlation factor for concentration; and figure 6, correlation factors for temperature and pressure. The variation in the correlation factors for concentration and pressure was insignificant. However, the temperature correlation factor exhibited greater variation, an indication of the responsiveness of the alkaline fuel cell to temperature.

Additional performance characterization testing of alkaline fuel cells would generate a statistical data base to develop an improved performance correlation factor for temperature and verify empirical performance factors for concentration and pressure.

The performance correlation permit cell voltage to be estimated at different operating conditions given the cell voltage at a known temperature, pressure, and concentration. The procedure for estimating cell performance is presented in table II. The three step process involves adjusting performance for concentration (eq. (1)) followed in turn by reactant pressure (eq. (2)) and adjustment for cell temperature (eq. (3)).

CATHODE CATALYST EVALUATION

An adjunct of the performance characterization tests was the exploratory evaluation of new gold-platinum cathode catalyst having the potential for improved performance. A trial laboratory cathode with each of the AuPt catalysts fabricated was performance tested before being assembled into a research cell. Test results provide a performance measure of the new cathode configurations. Cathode catalyst configurations and performance are summarized in table III. Performance of several AuPt catalysts in oxygen and air is presented in figure 7.

The best performance was achieved with the reference catalyst cathode. The reference catalyst with a measured surface area of 12 m²/g was the lowest of the fabricated catalysts. The improved AuPt and doped AuPt catalysts demonstrated a significantly higher surface area. Cathode performance and research

cell test results, however, did not achieve a performance level consistent with an improvement in catalyst surface area.

CONCLUSIONS

Additional research cell performance characterization tests are necessary to verify the applicability of the defined empirical performance factors for temperature, pressure, and concentration.

Evaluation of catalyst preparation techniques and additional electrode fabrication trials will be required to achieve the performance benefits of the high surface area doped AuPt catalysts.

ACKNOWLEDGMENTS

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TABLE I. - RESEARCH CELL CONFIGURATION SUMMARY

Cell	Cathode	Matrix	Anode/ERP
1	Improved AuPt	Potassium titanate	PtPd/porous graphite
2	Reference AuPt	↓	PtPd/porous nickel
3	Doped AuPt A		PtPd/porous nickel
4	Doped AuPt B		PtPd/porous graphite
5	Doped AuPt C		PtPd/porous graphite

TABLE II. - CELL PERFORMANCE PREDICTION PROCEDURE

A. Electrolyte concentration

$$E = E_o + C_F \left(\frac{C - C_o}{1000} \right) \quad (1)$$

- E = cell voltage at C, P_o, and T_o, V
- E_o = cell voltage at C_o, P_o, and T_o, V
- C_F = concentration correlation factor (fig. 5)
- C = desired concentration, wt % KOH
- C_o = known concentration, wt % KOH

B. Reactant pressure

$$P_F \left(\frac{P - P_o}{P P_o} \right) \quad (2)$$

$$E = E_o e$$

- E = cell voltage at C, P, and T_o, V
- E_o = cell voltage at C, P_o, and T_o, V
- P_F = pressure correlation factor (fig. 6)
- P = desired pressure, psia
- P_o = known pressure, psia

C. Cell temperature

$$T_F \left(\frac{T - T_o}{T T_o} \right) \quad (3)$$

$$E = E_o e$$

- E = cell voltage at C, P, and T, V
- E_o = cell voltage at C, P, and T_o, V
- T_F = temperature correlation factor (fig. 6)
- T = desired temperature, °F
- T_o = known temperature, °F

TABLE III. - CATHODE PERFORMANCE SUMMARY

Cathode catalyst	Oxygen performance, V		Tafel slope, mV/decade	Surface area, m ² /g
	10 ASF	100 ASF		
Reference AuPt	1.013	0.962	51	12
Improved AuPt	1.010	.952	58	19
Doped AuPt A	.988	.934	54	26.3
Doped AuPt B	.988	.941	57	23.7
Doped AuPt C	1.011	.944	67	27.1

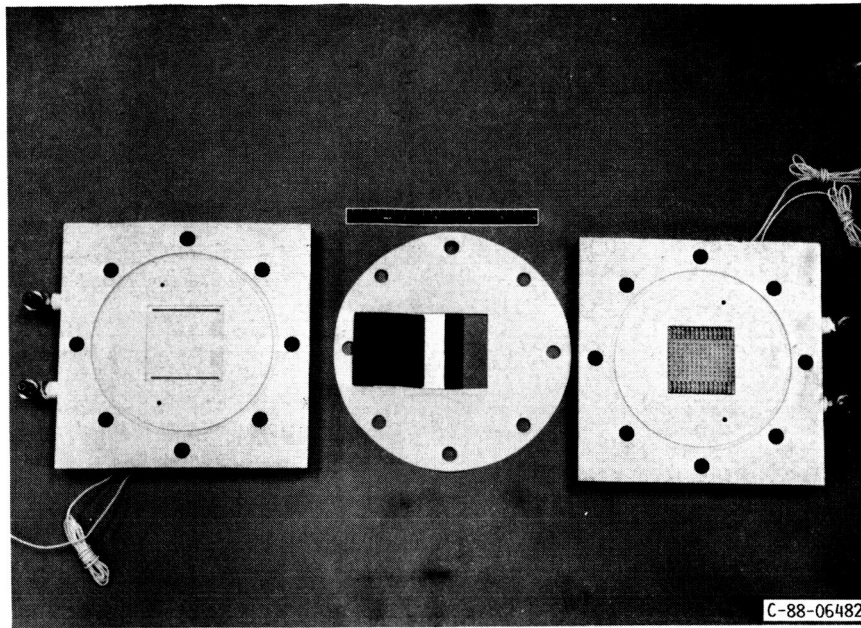


FIGURE 1. - TYPICAL RESEARCH CELL HARDWARE TEST SETUP.

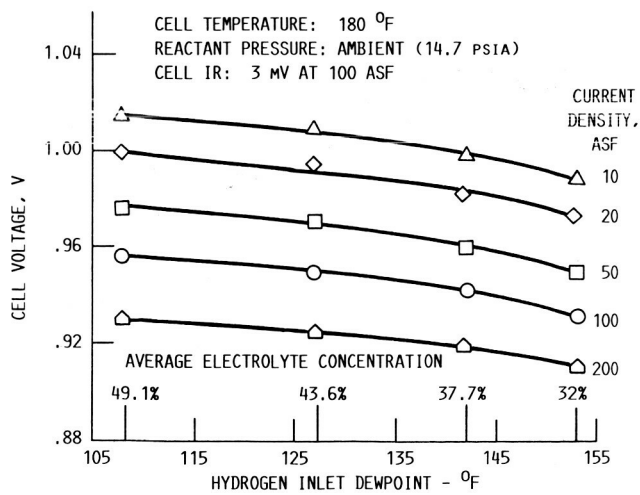


FIGURE 2. - PERFORMANCE RESPONSE TO CONCENTRATION. DATA CORRECTED FOR CELL IR.

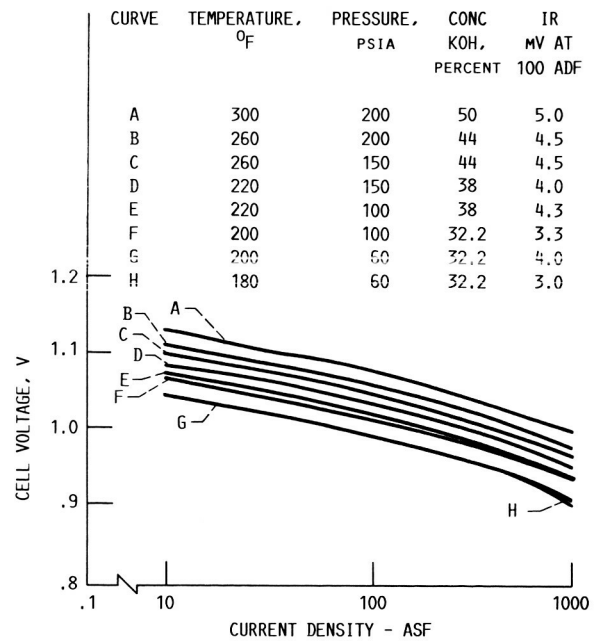


FIGURE 3. - PERFORMANCE RESPONSE TO TEMPERATURE AND PRESSURE.

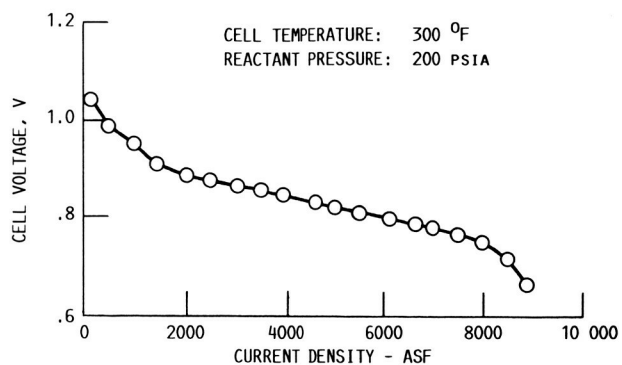


FIGURE 4. - PERFORMANCE CALIBRATION.

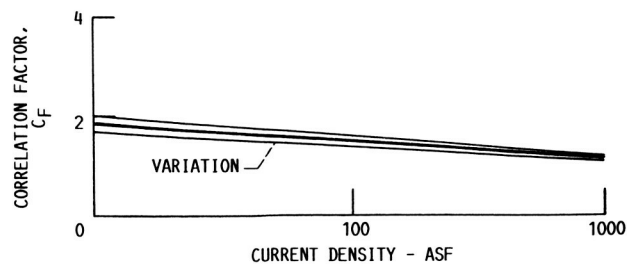


FIGURE 5. - PERFORMANCE CORRELATION FACTOR FOR CONCENTRATION.

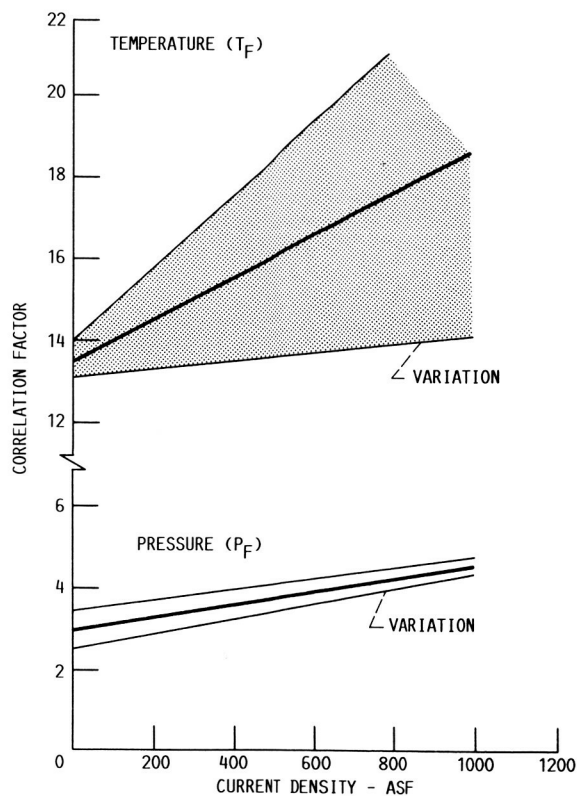


FIGURE 6. - PERFORMANCE CORRELATION FACTORS FOR TEMPERATURE AND PRESSURE.

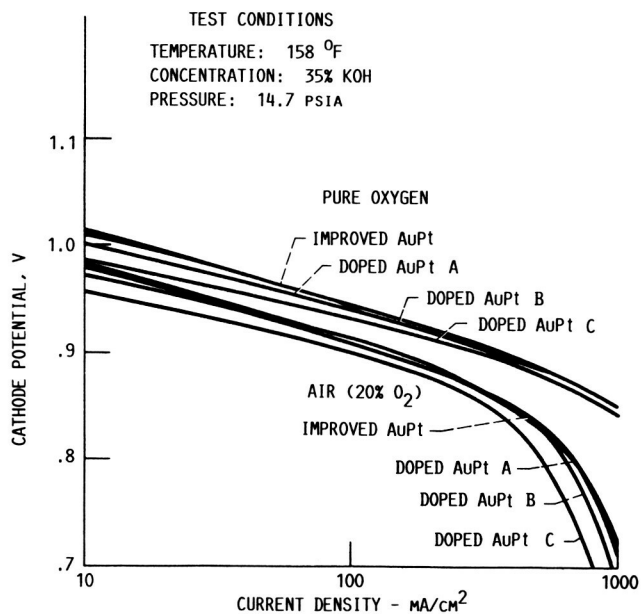


FIGURE 7. - PERFORMANCE OF AuPt CATALYSTS IN OXYGEN AND AIR.



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